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ACHIEVEMENTS IN THE FIELD OF SPACE MATERIALS SCIENCE AND THEIR USAGE IN INDUSTRY

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ABSTRACT. The unique environment encountered by objects launched into space creates special materials engineering problems. The authors describe several new types of materials designed to cope with space conditions, but valuable for Earth-surface use as well. They include: FT-40, an improved Teflon; heat resistant polymers; self-lubricating friction surfaces and low-volatility lubricants.

In the development of space engineering products, a number of problems are encountered related to the effects of the cosmic medium on objects manufactured from various materials. Space investigations have allowed us to establish the primary factors of surrounding space which may influence the properties of materials and the ability of units in spacecraft to perform. These include extremely low pressure (high vacuum), the short wave radiation of the sun, temperature fluctuation and the radiation effects of high energy particles. When these factors come into play, radiation damage and changes in the physical and mechanical characteristics of a number of plastics and elastomers are possible, as well as changes in the characteristics of optical materials and heat controlling coatings, disruption of the operation capacity of semiconductor devices, cold welding and sticking of contact pairs, friction couplings, etc. This causes a number of problems related to the selection of construction and other materials and, as will be shown below, the solution of these problems is important not only for space engineering, but also in such areas as electrovacuum engineering, nuclear power engineering, the chemical industry and elsewhere. /1[1]

In the process of studying the effectiveness of materials under space conditions, investigations have been performed so that as a final result it has been possible to recommend materials providing high reliability of apparatus under these conditions.

[1] Numbers in the margin indicate pagination in the foreign text.

The investigations performed have established that the factors occurring under space conditions have practically no influence on metal construction materials. One exception is the behavior of materials under low temperature conditions which may occur, for example, on the shaded side of space craft, on the surface of the moon, etc. In this case, many metallic materials have been found unable to retain their effectiveness under load. It has been established that the most reliable materials are aluminum alloys and stainless steel. For deep cold conditions, a number of high strength aluminum alloys, further strengthened by heat treatment, plus austenitic steels based on a well known composition (8% Ni and 18% Cr) have been developed and recommended for application both in space equipment and in various general purpose cooling equipments. Encouraging results have been produced by certain titanium alloys, distinguished by high specific strengths. /2

The behavior of a number of materials has been studied when subjected to both thermal and vacuum influences. Data have been produced on losses in weight, changes in physical and mechanical properties and the influence of oxide films on the evaporation of construction materials during long exposure to deep vacuum at various temperatures. It has been discovered that such coatings as cadmium and zinc, widely used under "terrestrial" conditions, evaporate quite easily in a vacuum when heated and therefore cannot be used in spacecraft structures. For these purposes, it is recommended that less volatile coatings such as nickel or chromium be used. Thin films used in optical parts may also be used for long term exposure to temperatures above 200°C.

The phenomenon of evaporation of materials may have unpleasant results in electronic equipment and electronic-vacuum devices, in which the metal evaporated during heating is deposited onto cold surfaces and forms a thin, current-conducting film capable of causing a short circuit. The most dangerous materials in this respect are cadmium, zinc and magnesium. One method of combatting evaporation, in addition to proper selection of materials, is the usage of chemical protective coatings (oxidation, phosphatization, etc.).

In order to assure the required temperature regime within various sectors of spacecraft, and for most economical maintenance of required temperature, materials must be created and used which have certain combinations of thermophysical properties, particularly insulation ability and thermal conductivity, and we must be able to determine these properties rather concretely. The accuracy of calculations on heat exchange is determined to a great extent by the accuracy of the characteristics included in these calculations. Determination of these characteristics must be performed in consideration of the broad range of temperatures on the surface of objects in space. The methods which we have developed have allowed us to measure the characteristics of radiation and thermal conductivity over a broad range of temperatures with sufficient accuracy. In those cases when the materials used do not satisfy the requirements for radiation and absorption surfaces, the problem has been solved by creating special coatings applied galvanically

and by other methods to the outer surface of the material of the apparatus.

Certain polymer materials change their mechanical properties under the influence of temperature and vacuum. This occurs primarily due to the rapid evaporation of the volatile components and low molecular fractions of the material. The strength of some materials may increase in a vacuum, while others lose strength; plasticity, fatigue and creep characteristics change. /3

For example, the well known polyvinyl chloride film used for insulation of wires and manufacture of domestic products becomes brittle and unsuitable for usage when exposed to a vacuum.

Due to its high heat resistance, high chemical resistance and good dielectric properties, fluoroplast 4 (Teflon) is widely used in various products. However, Teflon has cold flow properties, and, what is particularly unfortunate when used in spacecraft, insufficient resistance to radioactive radiation. The increased demands placed on the structures in spacecraft have led to the necessity of development of a new material with the useful properties of Teflon, but resistant to radioactive radiation. This material (FT-40) does not have cold flow, does not age, is resistant to penetrating radiation, can be formed by hot pressing, and can be welded and stamped. Also, it retains the positive properties of FT-4 [Teflon] to a great extent -- high chemical stability, heat resistance and very good dielectric properties. The new material FT-40, due to its high qualities, can be widely used in various areas of industry, particularly as a packing-sealing material and a material for friction couples operating in corrosive media.

The development of missile and space technology has led to the development of new types of plastics. For example, a number of plexiglass materials based on ester, phenol, epoxy and organosilicate binders have been developed. Testing of these materials under conditions simulating those in space has shown their good resistance to light-heat-vacuum aging, their resistance to thermal shock, to proton and gamma radiation. The beginning of thermal destruction, which is accompanied by a jump in the rate of gas liberation, for epoxy plastics is at 150-200°C, for organosilicate plastics -- at 300-400°C and for special modified type MF plexiglass materials -- at 450-475°C. The plexiglass materials used in space equipment can also be used broadly in industry as light and strong construction materials which retain their service properties well over long operating periods.

The influence of space conditions on the formation of radiation defects in materials has been investigated. The main reasons for the formation of defects have been radiation damage caused by high energy protons and electrons, as well as short wave solar radiation. Surface radiation damage has influenced primarily the optical properties of materials: the coefficients of reflection and absorption, optical transparency, the behavior of thin optical coatings, etc. /4

Some types of glass become dark when bombarded by high energy particles, and even plastiglas (polymethyl methacrylate), widely used in industry, becomes covered with a matte, nontransparent film under the influence of short wave ultraviolet radiation at doses equivalent to 20 days solar irradiation in space. These phenomena have led to the development of special glasses which do not change their optical characteristics under long term irradiation. These glasses are successfully used in the helmets of space suits and the hatches of spacecraft.

On the basis of diatomic phenols, a new type of heat resistant and radiation resistant material has been developed, the polyarylates; these materials can be formed into products by casting and direct pressing. Polyarylate is a radiation resistant material with high strength indicators (tensile strength up to 900 kg/cm^2, modulus of elasticity 6000-8000 kg/cm^2) and has good dielectric properties. A shock resistant polyarylate has been developed. Polyarylate films, in contrast to most dielectric films used in the past (lavsan, polycarbonate, PETR, etc.) changes its high dielectric properties only slightly in the temperature range from -60 to +250°C and higher. Heat resistant and chemical resistant coatings can be produced on the basis of polyarylates which are stable to the effects of many acids, oils and most organic solvents. Polyarylates can be used as a basis for the production of thermoreactive polymers and plastics with valuable properties; for example, rigid plastic foams based on polyarylates are stable up to 300°C, whereas the polyurethane foams widely used in industry are only stable up to 170-180°C.

Among the best polymer materials for work under high loads under space conditions are the polyimides. Investigations have shown that their radiation stability is unequaled among other polymers -- doses of gamma radiation, neutrons and fast electrons up to 10,000 Mrad do not cause their properties to deteriorate. The polyimides do not liberate volatile substances in a vacuum at temperatures up to 350°C, and are strong over a broad range of temperatures. The polyimide films are cold resistant down to -200°C and lower. In their mechanical properties, polyimides are superior to /5
materials such as Teflon, and are resistant to organic solvents, oils, fuels and dilute acids. Polyimide fibers are promising for usage under radiation conditions at high and low temperatures; in combination with polyimide plastics, they may be used for the manufacture of strong, light textolites with homogeneous electrical properties, which can be used for vehicle shells.

The usage of polyimides in electrical machines and electrical equipment allows:

a) an increase in the reliable temperature of long term operation to +250°C, and the provision of reliability in case of overheating in air up to 350-400°C for many hours;

b) a substantial (1.5-2 times) reduction in the weight/power ratio of electrical machines, which is particularly important for aviation and space uses;

c) the manufacture of radiation resistant apparatus;

d) a substantial increase in the reliability and operating life of electrical machines under difficult operating conditions.

Thermoplastic polyimides have very good technological properties: good casting qualities, and low shrinkage, which allows direct manufacture of fine, complex form parts.

The heat resistance of polyimides exceeds the heat resistance of all other types of plastics. A glass filled plastic based on polyimide (70% glass fiber) is as strong as the strongest available plexiglass and retains all the advantages of the polyimide.

One of the difficult problems related to the behavior of materials under space conditions has been the problem of friction, wear and the lubrication of friction surfaces. In a vacuum, liquid and grease lubricants evaporate with the passage of time. The working conditions of friction surfaces with no lubricant or natural contamination such as the oxide films usually present under terrestrial conditions are essentially worsened. Friction of these purified surfaces results in the formation of scratches, and seizing and cold welding of friction surfaces becomes possible. The necessity arises of developing lubricants which can guarantee the operating time of friction couples under high vacuum conditions over a broad range of temperatures, which have radiation resistance, which are insensitive to weightlessness and sharp changes in velocity vectors.

These conditions are satisfied to a great extent by solid lubricants and self-lubricating materials. These lubricants can be used in the form of powders, thin coatings or self-lubricating construction materials. Solid lubricants which can be used include layered inorganic materials: MoS_2, WS_2, $MoSe_2$, graphite, etc. The most widely used for space purposes have been /6
those based on molybdenum disulfide MoS_2, which has low evaporation in a vacuum and good heat resistance and radiation resistance. Lubricants based on MoS_2 with binders consisting of various resins (for example organo-silicates) can be applied to metal friction surfaces. These lubricants have been highly effective during operation in a vacuum, although the operating life of these lubricants is limited by their evaporation time. In order to increase the operating life, a number of self-lubricating materials have been created, for example, compositions containing polyfluoroethylene resin sintered with silver or copper, parts made of molybdenum disulfide with polyarylates and phenol resin binders (so-called amanes), and metallopolymer compositions. These self-lubricating materials are used to make ball-bearing separators, gears, and friction bearing inserts. The wear resistance of metallopolymer compositions based on Teflon is much greater than the wear resistance of tin bronze and other metals.

The solid lubricants and self-lubricating materials developed for space engineering products can be used in industrial installations and devices which include units rotating in a vacuum.

In this report, due to its limited volume, we have been able to present only a comparatively small number of examples of the solution of specific problems of space materials research, and to show the possibilities of the industrial application of materials developed for space engineering purposes. The advantages of the usage of these materials in terrestrial apparatus and instruments operating under difficult temperatures, radiation and other conditions are obvious.

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